Effects of Stimulus Presentation Modes on Tactual Letter Recognition

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EFFECTS OF STIMULUS PRESENTATION MODES ON TACTUAL LETTER RECOGNITION

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The present paper deals with the ability of subjects to identify raised patterns presented to their index finger. The patterns were raised capital letters of the alphabet produced by the stereo copying system. Three different modes of stimulus presentation were examined at two letter heights: (1) the active scanning mode, (2) the passive static mode and (3) the passive scanning mode. The results of eight trained subjects showed that the two scanning modes yielded similar performance in recognition accuracy, and performance was always better than in the static mode. The correlation coefficients computed separately for the hit rates and for confusion error values were high between the two scanning modes at two letter hights. The similarity of the two scanning modes supports the idea that pattern information essential for tactual pattern recognition is the one that continuous deformation between the skin and the letter will produce, and that kinesthetic information will not necessarily be needed. From the additional results of hierarchical clustering analysis, some speculations were made on the tactual processing of letters.

Key words: active touch, passive touch, tactual scanning, kinesthetic information

INTRODUCTION

In research of tactual perception, much work has been done about the stimulus presentation mode. This work has mainly aimed at improving more effective communication devices for sensory substitution and making the functioning of the cutaneous sense clear (Loomis & Lederman, 1986). Roman letters and cookie-cutter shapes have been used as the stimulus materials of two-dimensional patterns. The studies on tactual recognition and identification of these patterns would be classified into two situations with regard to the presence of the motor control: One is the passive situation in which the tactual stimulus was presented beneath the stationary finger, using TVSS and Optacon (Craig, 1981; Kikuchi, Yamashita, Sagawa & Wake, 1979; Loomis, 1974, 1982). In this mode, whether the presence of the movement of the letter itself or the spatio-temporal changes accompanied by the presentation of the letter takes effect on letter recognition has been discussed. The other is the situation in which subjects actively touched the stimulus or were passively touched by the stimulus (Heller, 1986, 1989; Loomis, 1985; Magee & Kennedy, 1980; Phillips, Johnson & Browne, 1983). In the former passive situation, there is little variation in contact

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between the skin and the stimulus, so that the spatio-temporal sensitivity of the skin per se can be determined. In the latter one, the superiority of active and passive touch, as proposed by Gibson (1962), has become a matter of great concern. In general, it has been reported that active touch led to superior recognition performance than did passive touch (Heller, 1986, 1989 ; Loomis, 1985 ; Phillips et al., 1983).

The superiority of active touch over passive touch, however, has been drawn from results of the inadequate experimental conditions. For example, in some experiments, relative large patterns that kinesthetic information was needed in recognizing were used. In others, the scanning mode (active touch), in which information on the stimulus was fed sequentially, was compared with the static mode (passive touch), in which information was fed simultaneouly. In these experiments, there is a possibility that another factors than variables being manipulated may influence the results. Thus, the problem of the superiority of active or passive touch must be examined in terms of information available to subjects.

The present experiment is concerned with effects of the presentation modes on tactual letter recognition. The problem of the superiority of active and passive touch was examined, using relative small letters which allowed their whole shape to be contact with a single finger. Furthermore, by analyzing error patterns, stimulus information that was easily extracted in a particular mode was specified.

Methods

Subjects : Eight male student voluntees, ranging in age from 21 to 24 years old, participated in this experiment. Seven of them were right-handed, and the other was left-handed. All eight subjects were naive in experiments on touch.

Stimuli : The tactual stimuli were raised capital letters of the alphabet produced by the stereo copying system. The letters were taken from Helvetica Letraset sheet. The average dimensions of the 26 letters were 10.0 mm high, 8.4 mm wide and 2.0 mm in stroke width. Two sets of the letters were prepared, one of 100% magnification (10-mm-height letters) and the other of 71% magnification (7.1-mm-height letters). By using the stereo copying system, these letters were raised on each card of capsule paper. Furthermore, since the raised letters would be worn out because of the contact between the letters and the skin, several pairs of these sets were prepared.

Modes of touch : The 26 letters were sensed in either of three modes using the right index finger. In the active scanning mode, the letter was stationary, and the subject was free to tactually scan the letter with any force, velocity and direction. In the passive static mode, the letter was stationary in position below the finger. The finger was constrained to allow only vertical movement to contact the letter ; no lateral motion during contact was permitted. In the third mode, the passive scanning mode, the finger was stationary, and the letter was moved relative to the finger. A constant velocity of the letter could be gained through an interposed toothed belt drive

Table 1. Comparisons of the three modes used in the experiment.

	Motor Control	Stimulus Presentation	Available Information
1. Active scanning	Control	Sequential	Cutaneous + kinethesis
2. Passive static	No-control	Simultaneous	Cutaneous
3. Passive scanning	No-control	Sequential	Cutaneous

with the stepping motor. In this mode, to avoid the spatial ordering error when presenting the letter, each letter was moved once back and force, either from right side of the letter or from left side. In all three modes, the contact time between the letter and the skin was held constant at 2 sec. Thus, in the passive scanning mode, each letter was moved at a speed of 8.4 mm/sec for the 10-mm-hight condition, and 6.0 mm/sec for the 7.1 mm height (71% magnification).

In terms of the type of information available to the subject (Loomis & Lederman, 1986), the three modes mentioned above would be summarized in Table 1.

Procedure : Before the experiment, the subject was told that the 26 capital letters of the alphabet were presented below the fingerpad and that he depressed the letter, or scan it, synchronizing with the warning signal, a 1000 Hz pure tone. After contacting the letter for 2 sec, he was asked to identify it. No equivocal responses were allowed, but he was given feedback on correct response after each trial. The interstimulus interval was about 10 sec, which allowed the experimenter to manually replace the card on which the letter was raised.

Each session of 2-h duration consisted of 312 presentations, 3 modes of touch by 2 sets of letter hight, 26 letters and 2 repetitions. Every 13 trials, the condition was changed, with the orders of conditions and letters to be presented within each condition being quasi-random. At the change of the condition, the subject was informed of the next condition and required to move his finger suitable for it. All eight subjects participated for 5 sessions, with data from only the last two sessions being included in the analysis.

Results

Recognition accuracies : Figure 1 shows the recognition accuracies, averaged over all eight subjects and the 26 letters, as a function of session. Though all subjects had had no experience in touch experiments, their performance level increased in almost all conditions as they were more trained. After the 4th session, however, there could be shown little improvement in performance. As mentioned above, further analysis were made based on data from the 4th and 5th sessions.

The average recognition accuracies as a functin of mode and letter height are shown in Fig. 2. A three-way analysis of variance with repeated measures was

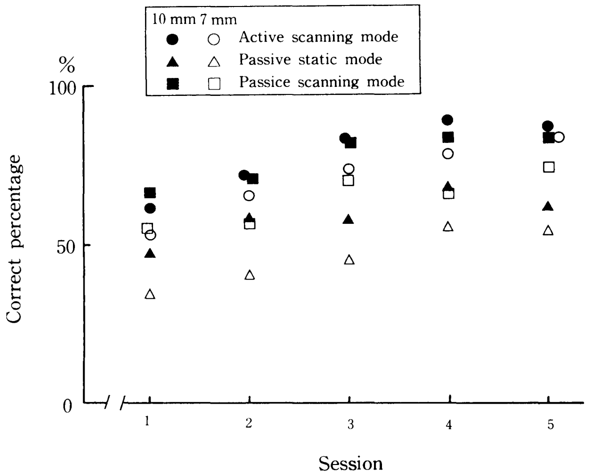

Fig. 1. Recognition accuracy (correct percentage) as a function of session, mode of touch and letter height. Filled marks show the 10 mm height condition, and open marks do the 7 mm hight.

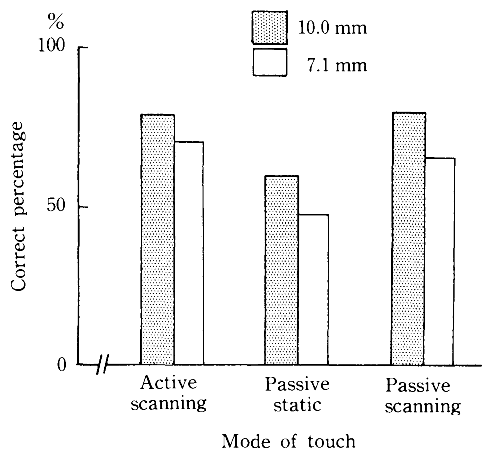

Fig. 2. Recognition accuracy as a function of mode of touch and letter height. Each bar was based on the data averaged over all the 26 letters.

performed on data transformed to sine-inverted scores, the factors being mode, letter height and subject. Main effects of mode and letter height were statistically significant ($F(2, 14)=31.80$, $p<.01$; $F(1, 7)=399.31$, $p<.01$, respectively). A significant intreraction effect, mode by letter height, was not found; that is, in all modes the recognition accuracies increased with increase in letter height. For post hoc comparisons, the Turkey method was used at each of the two heights. In both of the two heights, significant differences were found between the two scanning and passive static modes, but there was no significant difference between the two scanning modes.

(a)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	
A	29	.	.	.	.	.	.	.	.	1	.	1	.	.	.	1	.	.	.	.	.	.	.	.	.	.	32
B	.	18	.	4	4	.	.	.	.	1	.	.	.	1	.	.	.	3	.	.	1	.	.	.	.	.	32
C	.	.	27	.	1	.	2	.	.	.	1	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	32
D	.	3	.	17	.	.	.	.	.	.	.	.	.	.	10	.	1	1	.	.	.	.	.	.	.	.	32
E	.	.	1	.	27	.	1	.	.	.	1	.	1	.	.	.	.	1	.	.	.	.	.	.	.	.	32
F	.	.	.	.	1	25	.	.	.	.	.	.	.	.	.	5	.	1	.	.	.	.	.	.	.	.	32
G	.	4	1	2	.	.	10	.	.	.	.	.	2	.	.	.	8	2	3	.	.	.	.	.	.	.	32
H	.	.	.	.	1	1	.	12	.	.	1	.	4	7	.	.	1	.	.	.	1	.	1	2	.	1	32
I	.	.	.	.	.	.	.	.	32	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	32
J	.	.	.	.	.	.	.	.	.	32	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	32
K	.	.	.	.	3	.	.	.	.	.	20	.	.	.	.	.	.	4	.	.	.	.	.	3	.	2	32
L	.	.	.	.	.	.	.	.	.	.	.	32	.	.	.	.	.	.	.	.	.	.	.	.	.	.	32
M	.	1	.	.	1	.	1	2	.	1	.	.	11	3	.	.	.	.	.	.	2	.	7	1	.	2	32
N	.	.	.	.	.	1	.	9	1	2	.	.	6	10	.	.	.	.	.	.	.	.	2	1	.	.	32
O	.	.	.	1	.	.	.	.	.	.	.	.	.	.	31	.	.	.	.	.	.	.	.	.	.	.	32
P	.	1	.	.	.	5	.	.	.	1	.	.	.	.	.	25	.	.	.	.	.	.	.	.	.	.	32
Q	.	.	.	2	.	.	2	.	.	.	.	.	.	.	4	.	21	1	.	2	.	.	.	.	.	.	32
R	1	.	1	1	1	.	1	3	.	.	.	.	.	2	.	.	1	21	.	.	.	.	.	.	.	.	32
S	.	11	.	.	.	1	1	.	.	.	.	.	.	.	5	.	.	2	12	.	.	.	.	.	.	.	32
T	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	27	.	.	.	2	.	2	32
U	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	29	2	.	.	.	.	32
V	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	1	27	.	1	2	.	32
W	.	.	.	.	.	.	.	.	.	.	.	.	6	.	.	.	.	.	.	.	.	.	26	.	.	.	32
X	.	.	.	.	1	.	.	.	.	.	1	.	1	2	.	.	.	1	1	.	.	.	.	16	.	9	32
Y	.	.	.	.	.	.	.	.	.	1	.	.	1	.	.	.	.	.	.	1	1	2	.	.	26	.	32
Z	.	.	.	.	2	1	.	.	.	.	.	2	.	.	.	.	.	2	.	.	.	.	.	1	.	24	32
	30	38	30	27	42	34	18	26	33	39	25	35	32	27	51	31	32	39	16	30	35	31	36	27	28	40	

(b)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	
A	28	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	1	.	2	32
B	.	14	1	1	2	1	4	.	.	.	.	1	3	1	.	1	.	1	2	.	.	.	.	.	.	.	32
C	.	.	20	2	.	.	3	.	.	.	.	.	.	.	1	1	5	.	.	.	.	.	.	.	.	.	32
D	.	4	.	16	.	1	1	.	.	.	.	.	.	1	1	3	2	1	.	.	2	.	.	.	.	.	32
E	.	4	.	2	12	2	.	.	.	.	.	.	1	.	1	2	.	4	2	.	.	.	2	.	.	.	32
F	.	1	.	.	.	20	.	.	.	.	1	.	1	.	1	5	.	.	.	1	.	.	.	.	1	1	32
G	1	5	.	.	.	.	18	.	.	1	.	.	.	.	2	1	.	1	2	.	.	.	.	.	.	1	32
H	.	1	.	.	.	.	.	14	.	.	.	.	8	5	.	.	.	.	.	.	1	1	2	.	.	.	32
I	.	.	.	.	.	.	.	.	30	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	32
J	.	.	.	.	.	.	.	.	.	30	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	1	32
K	.	.	.	.	4	1	.	2	.	.	15	1	.	3	.	.	.	1	.	.	.	.	2	1	1	1	32
L	.	.	.	.	.	.	.	.	1	.	.	31	.	.	.	.	.	.	.	.	.	.	.	.	.	.	32
M	.	1	.	.	.	.	.	2	.	.	1	.	12	10	.	.	.	.	.	.	1	.	3	.	2	.	32
N	.	.	.	.	.	.	.	6	.	.	2	.	4	13	.	.	.	.	.	.	.	.	4	1	2	.	32
O	.	.	1	4	.	.	1	.	.	.	.	.	.	.	23	.	3	.	.	.	.	.	.	.	.	.	32
P	.	1	1	.	.	9	.	.	1	1	.	.	.	.	.	14	2	.	.	3	.	.	.	.	.	.	32
Q	.	.	4	5	.	.	3	.	.	.	.	.	.	.	9	.	5	3	.	.	1	.	.	.	2	.	32
R	2	1	.	2	3	1	.	4	.	.	1	.	1	1	.	2	.	11	.	1	2	.	.	.	.	.	32
S	.	2	2	.	1	1	4	.	.	.	.	.	.	1	2	1	2	.	16	.	.	.	.	.	.	.	32
T	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	28	.	.	.	1	2	.	32
U	.	.	.	.	.	.	.	1	.	1	.	.	.	1	.	.	.	.	.	.	27	1	1	.	.	.	32
V	.	.	.	.	.	.	.	1	.	1	.	.	1	1	.	.	.	.	.	.	1	18	.	.	9	.	32
W	.	.	.	.	.	.	.	.	.	.	.	.	2	2	.	.	.	.	1	.	.	1	23	2	.	1	32
X	.	.	.	.	4	.	.	2	.	1	9	.	1	2	.	1	1	2	.	1	.	.	.	7	1	.	32
Y	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	5	.	.	25	.	32
Z	.	.	.	.	2	1	.	.	.	.	2	1	.	1	.	.	.	1	.	.	.	.	.	5	.	19	32
	31	34	29	32	28	38	34	32	32	35	31	36	34	42	40	32	20	27	23	35	35	26	37	18	45	26	

(c)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	
A	21	.	1	.	1	1	.	.	1	2	.	3	.	.	.	.	.	1	.	.	.	.	.	.	.	1	32
B	.	9	.	5	3	.	4	.	.	.	.	.	2	.	4	2	.	.	3	.	.	.	.	.	.	.	32
C	.	.	20	1	.	.	.	.	.	1	1	2	.	.	1	.	2	2	1	.	.	.	.	.	.	1	32
D	.	3	3	6	2	.	.	.	.	.	.	.	.	5	1	2	3	1	2	.	1	.	2	.	.	1	32
E	.	2	.	2	8	3	.	.	.	.	2	.	2	3	.	2	2	2	2	.	.	.	.	.	.	2	32
F	2	1	.	1	1	9	.	.	.	.	.	.	.	.	.	5	1	2	.	5	.	1	.	.	3	1	32
G	1	2	4	4	2	1	4	.	.	.	.	.	1	.	1	.	5	3	1	.	1	1	.	.	.	1	32
H	.	1	.	.	.	.	.	11	.	1	1	.	2	6	.	.	.	.	.	.	7	.	2	.	1	.	32
I	.	.	.	.	.	.	.	.	32	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	32
J	.	.	.	.	.	.	.	.	2	29	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	32
K	.	.	.	.	3	2	.	2	.	.	10	.	.	1	.	.	.	3	.	2	.	1	1	5	1	1	32
L	.	.	.	.	.	.	.	.	.	.	.	32	.	.	.	.	.	.	.	.	.	.	.	.	.	.	32
M	.	.	.	1	.	2	.	.	.	.	3	.	12	2	.	.	.	.	.	.	2	1	9	.	.	.	32
N	.	.	.	.	.	.	.	4	.	.	.	.	4	10	.	1	.	.	.	.	6	1	4	.	2	.	32
O	.	.	1	3	.	1	1	.	.	.	.	.	.	.	20	.	3	1	1	.	1	.	.	.	.	.	32
P	1	1	.	.	1	4	.	.	.	.	.	.	.	.	3	17	.	.	1	3	1	.	.	.	.	.	32
Q	.	3	4	7	.	.	2	.	.	.	.	1	.	.	1	.	9	3	1	.	.	.	.	.	1	.	32
R	.	10	.	3	2	.	.	1	.	.	.	.	3	2	.	4	.	4	1	.	.	.	2	.	.	1	32
S	.	6	2	1	.	.	2	.	.	.	1	.	.	.	3	.	2	3	10	.	.	.	.	1	.	1	32
T	.	.	.	.	.	.	.	.	1	.	.	.	.	2	1	.	.	.	.	26	.	.	.	.	2	.	32
U	.	.	1	.	.	.	1	3	.	.	.	.	2	2	.	.	1	.	.	.	20	1	.	.	.	1	32
V	.	.	.	.	.	1	.	1	.	4	.	.	1	2	.	.	.	1	.	2	1	12	.	.	7	.	32
W	.	.	.	.	.	1	.	2	.	.	.	.	7	.	.	.	.	.	.	1	.	1	19	.	.	1	32
X	1	.	1	.	2	2	.	1	.	2	1	1	1	3	.	.	.	3	.	2	.	1	.	6	3	2	32
Y	.	.	.	.	.	1	.	.	.	1	1	.	.	.	.	.	.	.	.	6	1	2	.	.	20	.	32
Z	.	.	.	1	9	.	.	1	.	1	2	.	.	.	.	1	.	1	.	.	.	.	.	.	.	16	32
	26	38	37	35	34	28	14	26	36	41	22	39	37	38	35	34	28	30	23	47	41	22	39	12	40	30	

Fig. 3. Confusion matrices constructed from the pooled data of the eight sujects for (a) the active scanning mode at 7 mm in height, (b) the passive static mode at 10 mm and (c) the passive static mode at 7 mm. Matrices for the other conditions were omitted for simplification.

The main purpose in the experiment was to examine the effects of the presentation modes. Quantitatively, it could be said that the performance level in the active scanning and that in the passive scanning were almost the same.

Confusion matrices: To examine the qualitative aspects of the presentation mode, the confusion matrices for each condition across a large number of stimuli were constructed (Figure 3.(a)-(c)). Based on these pooled confusion data, the following analysis were done: the estimates of each letter tangibility (Loomis, 1982), the calculations of the correlations between each matrix (Craig, 1979; Phillips et al., 1983) and hierarchical clustering schemes (Johnson, 1967; Kikuchi et al., 1979; Loomis, 1982).

To estimate the relative tangibility of each letter in the six conditions, signal detection theory was used. The hit rates corresponded to the probabilities of the

Table 2. Estimates of A′ for the six conditions.

	Active scanning		Passive static		Passive scanning	
	10 mm	7 mm	10 mm	7 mm	10 mm	7 mm
A	.796	.976	.968	.911	1.00	.951
B	.916	.877	.842	.781	.869	.860
C	.992	.960	.901	.896	.998	.936
D	.983	.875	.862	.741	.983	.919
E	.919	.955	.827	.774	.948	.876
F	.968	.941	.895	.795	.951	.879
G	.901	.818	.880	.753	.893	.792
H	.849	.829	.843	.819	.897	.837
I	1.00	.999	.984	.999	1.00	1.00
J	.999	.998	.983	.972	.999	.999
K	.953	.903	.854	.814	.950	.932
L	.999	.999	.991	.998	.999	.992
M	.922	.812	.821	.818	.853	.807
N	.806	.807	.824	.794	.840	.869
O	.962	.989	.921	.897	.956	.982
P	.983	.942	.843	.870	.943	.933
Q	.909	.908	.955	.795	.870	.807
R	.934	.904	.818	.709	.909	.862
S	.875	.840	.869	.812	.901	.799
T	.945	.960	.966	.944	.938	.913
U	.998	.974	.958	.893	.990	.969
V	.960	.959	.885	.833	.973	.877
W	.957	.949	.922	.885	.974	.936
X	.924	.866	.786	.785	.971	.925
Y	.942	.952	.936	.894	.941	.970
Z	.957	.930	.894	.864	.919	.939

diagonal cells; the false-alarm rates to the mean probabilities of the letter being identified as the other 25 letters except for the letter i, when the the letter i was presented. On the assumption that the distributions of the hit and false-alarm rates were normal with equal variance, d′ has been treated as a measure of combining hit and false-alarm rates. To avoid this stronger assumption, however, the A′ values, one of the non-parametric measures (Rae, 1976), were used as tangibility of the letters. Table 2 shows the estimates of A′ for each letter in the six conditions. Letters having the higher A′ values in all conditions were I, J and L, which were consisted of a few lines; whereas letters having the lower A′ values were B, G, H, N and S.

From the results of ANOVA for recognition accuracies, no differences were found between the active and passive scanning modes in both letter heights. Then, qualitatively, will the differences be found between the two conditions? Pearson product-moment correlation coefficients were computed for assessing the similarity of the two modes. For the 10-mm-height condition, the correlations between the two modes were .74 for the hit rates and .52 for the (no-symmetrized) off-diagonal values; for the 7-mm-height, the values were .78 for the hit rates and .54 for the off-diagonal values. These correlations were a little lower than the values reported by Phillips et al. (1983), but it could be suggested that information processing in both two modes was quite similar.

At the next stage, cluster analysis was done for the confusion error data to determine the similarity between each letter. This analysis was applied to the off-diagonal values in the passive static modes at 7 mm and 10 mm and the active scanning mode at 7 mm, since there was a possibility that one error in each matrix would be overestimated when the hit rates were higher. As a measure of similarity, a formula by Kikuchi et al. (1979) was used, and the furthest neighbor method was employed. The results of the three analysis are shown in Figure 4.(a)-(c).

Discussion

As seen in Fig. 1, at the early period of learning letters, recognition accuracies in the passive scanning modes were a little higher than those in the active scanning modes. Also, from introspection of all eight subjects, it was reported that, at first, being passively touched by letters was made easier than touching letters actively; whereas, at the last 3 or 4 sessions, the result was reversed. Heller (1986) has pointed out that active scanning may be helpful during early phases of learning, but the opposite result was obtained in this experiment. It is highly probable that the subjects in his experiment were highly trained within one trial, since the exposure time of patterns was longer, 15 sec. Hence, at the early period, motor guidance, as Magee & Kennedy (1980) has pointed out, may be effective in leaning letters, and at the latter one, active scanning in which the features of the letters were freely extracted by subjects would be effective.

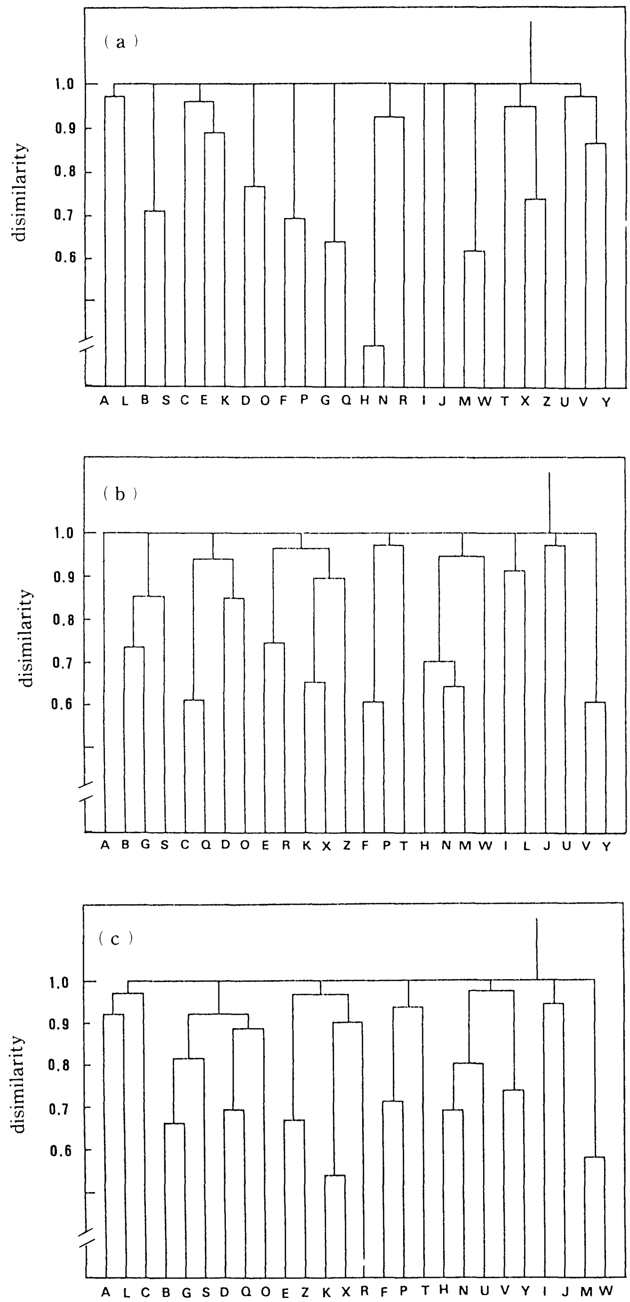

Fig. 4. The results of the cluster analysis for (a) the active scanning mode at 7 mm, (b) the passive static mode at 10 mm and (c) the passive static mode at 7 mm. These results were based on the matrices illustrated in Fig. 3.

With regard to the effects of modes, the significant difference was not found between the active and passive scanning modes for recognition accuracies. By the relative movement between the skin and the letter, the performance level increased compared with the stationary condition. Since the correlations between the two matrices were high for both letter heights, it would be considered that the similar features of the lettter were extracted in the two modes. Thus, it can be concluded that pattern information essential for recognizing letters tactually is the one that continuous deformation will produce, and that, if small letters, as contacted with a single finger, are presented sequentially, kinesthetic information is not necessarilly needed.

As shown in Fig. 4, the results of cluster analysis, the whole confused patterns were similar to those of experiments of Kikuchi et al. (1979) and Loomis (1982), which differed in locus of stimulus presentation and the presentation mode. Letters highly confusable with each other were B-G-S, C-D-Q-O, E-R-Z-K-X, F-P-T, H-N-U-V-Y- and M-W. As Loomis (1974, 1980, 1982) has pointed out, the superiority of sequential presentation probably applies in situations where the patterns are small relative to the spatial resolution of the skin.

Compared with cluster analysis in the two static modes (Fig. 4, (b) and (c)), confusable letters were identical in the scanning mode; however, in the scanning mode, each cluster was almost dependent, and was not fused with the stronger cluster in the course of clustering. Letters having low tangibility values in the static mode, E, K, Q, and X were confusable with other letters, but, in the scanning, these letters had low similarity values to others. In considering the feature extraction in the modes, letters having similar features in construction cannot be easily discriminated in the static mode; however, in the scanning mode, the relative discrimination can be improved. But discrimination between letters sharing the features in edge remains impaired.

Heller (1989) has pointed out that the effect of tactile tracing was due to two-dimensional input being translated into kinesthetic movement patterns; however, from introspection of subjects, this was not true when using small patterns. First, the global features of the pattern, and then, the local features would be extracted in the top-down processing. Loomis (1974) has proposed a theory of cutaneous form perception, on the basis of spatial frequency analysis. As applying his theory to heuristics of subjects, it could be interpreted that, first, their lower spatial frequency components of letters, and then, their higher components were extracted. However, whether it is reasonable to consider that the cutaneous system like this analyzes the stimulus in terms of spatial frequencies or geometric features will have to be examined more directly. For example, in research of visual processing of letters (Gervais, Harvey Jr. & Roberts, 1984), the validity of several models of visual processing has been tested after visual stimuli were determined in spatial frequency domain or represented by the number of times of the geometric features appeared in the letter. Thus, in the present stage, it cannot be specified what information about the stimulus is analyzed in the central neural processing.

These results were derived from a fixed duration and relative small patterns, and as Craig (1981) and Loomis (1980) have pointed out, there is a possibility that the effects of modes will change as a function of exposure time and letter size. Further research will be necessary on this point.

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References

Craig, J.C. **1979** A confusion matrix for tactually presented letters. *Perception & Psychophysics*, **26**, 409-411.

Craig, C.C. **1981** Tactile letter recognition: Pattern duration and modes of pattern generation. *Perception & Psychophysics*, **30**, 540-546.

Gervais, M.J., Harvey, L.O., Jr., & Roberts, J.O. **1984** Identification confusions among letters of the alphabet. *Journal of Experimental Psychology : Human Perception and Performance*, **10**, 655-666.

Gibson, J.J. **1962** Observations on active touch. *Psychological Review*, **69**, 477-491.

Heller, M.A. **1986** Active and passive tactile braille recognition. *Bulletin of the Psychonomic Society*, **24**, 201-202.

Heller, M.A. **1989** Effect of tactual scanning mode on braille and shape recognition. *Bulletin of the Psychonomic Society*, **27**, 131-132.

Johnson, S.C. **1967** Hierarchical clustering schemes. *Psychometrika*, **32**, 241-254.

Kikuchi, T., Yamashita, Y., Sagawa, K., & Wake, T. **1979** An analysis of tactile letter confusions. *Perception & Psychophysics*, **26**, 295-301.

Loomis, J.M. **1974** Tactile letter recognition under different modes of stimulus presentation. *Perception & Psychophysics*, **16**, 401-408.

Loomis, J.M. **1980** Interaction of display mode and character size in vibrotactile letter recognition. *Bulletin of the Psychonomic Society*, **16**, 385-387.

Loomis, J.M. **1982** Analysis of tactile and visual confusion matrices. *Perception & Psychophysics*, **31**, 41-52.

Loomis, J.M. **1985** Tactile recognition of raised characters: A parametric study. *Bulletin of the Psychonomic Society*, **23**, 18-20.

Loomis, J.M., & Lederman, S.J. **1986** Tactual perception. In K.R. Boff, L. Kaufman & J.P. Thomas (eds.) *Handbook of perception and human performance. vol. 2.* A Wiley-interscience Publication.

Magee, L.E., & Kennedy, J.M. **1980** Exploring pictures tactually. *Nature* (London), **283**, 287-288.

Phillips, J.R., Johnson, K.O., & Browne, H.M. **1983** A comparison of visual and two modes of tactual letter resolution. *Perception & Psychophysics*, **34**, 243-249.

Rae, G. **1976** Table of A′. *Perceptual and motor skills*, **42**, 98.

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